

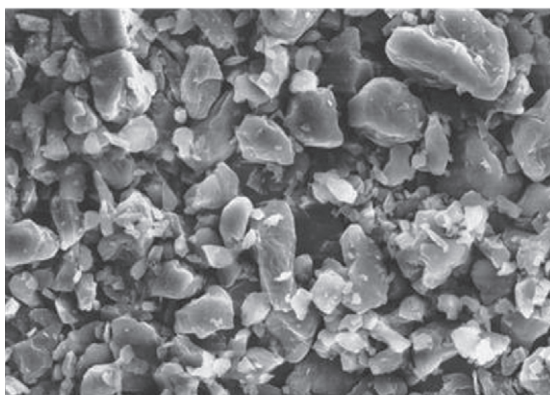
JULY/AUGUST 2008
Volume 15, Number 4

Journal of **CHEMICAL** Health & Safety

Evaluation, Airborne Release Fractions, and

Control of Beryllium Hazards at

Los Alamos National Laboratory



Impact Ground Be Powder

-
Scopus is the largest abstract and citation
database of peer-reviewed literature and
quality web sources with smart tools to track,
analyze and visualize research.
-

-
**enrich
your
experience**
-

-
www.scopus.com
-

refine your research
SCOPUS™

Beryllium: Hazards evaluation, facility classification, consequence analysis of releases during potential accidents, and protection of public and workers

By J.C. Laul, Rich Norman

Comprehensive literature searches on beryllium (Be) and information on the particle size distribution of Be powder (Mishima et al.)^{1,2} indicate that the new airborne release fraction/respirable fraction (ARF/RF) values for large coherent pieces, turnings/swarfs, chips/powder, and dust are several orders of magnitude lower for explosion, fire, and spill (e.g., $1\text{E}-2$, $1.5\text{E}-5$, $1\text{E}-6$) than earlier estimates based on DOE-HDBK-3010.³ This implies a lower consequence exposure and thus an increase in threshold limit or lower facility hazard classification (High–Moderate–Low), and less risk of exposure to workers and public during these accident scenarios. This is demonstrated by a case study of using 100 lbs chips/powder under various accident conditions (explosion, fire, and spill) in standard terrain (rural) and city terrain (urban) to assess the relative concentrations to a receptor at different distances, using EPIcode (Emergency Prediction Information Code) dispersion model.

Beryllium aerosol exposure can cause: (1) acute exposure (short term) from Emergency Response Planning Guideline-3, -2 (ERPG-3, -2) levels; and (2) chronic (long term) from sensitization and chronic beryllium disease (CBD). Per 40 CFR 61.32, the Environmental Protection Agency (EPA) Be emission standard limit to protect the public (no CBD) is $0.01\text{ }\mu\text{g}/\text{m}^3$ on a 30-day time weighted average (TWA).⁴ Facility hazard classifications require modeling to be performed to establish a distance beyond which the public is protected. A case study using 100 lbs chip/powder release with conservative assumptions (e.g., standard, term release) shows that the public is protected beyond 200 m.

The American Conference of Government Industrial Hygienists (ACGIH)⁵ and Occupational Safety and Health Administration (OSHA) adopted exposure threshold limit value for workers at $2.0\text{ }\mu\text{g}/\text{m}^3$, based on 8-hr TWA. However, 10 CFR 850 Rule on CBD and Prevention Program⁶ requires a protection at $0.2\text{ }\mu\text{g}/\text{m}^3$ (8 h TWA), to further mitigate or prevent any health effects or CBD. Thus, 40 CFR 61.32, ACGIH and OSHA guide, and 10 CFR 850 Rule, coupled with the worker protection program and adequate safety controls, provide adequate protection from the CBD to the workers and public.

INTRODUCTION

Beryllium is a strategic metal with unique physico-chemical properties that make it indispensable in the aerospace, ceramics, nuclear, and telecommunication industries, as well as for other products in common use. Beryllium has special place in nuclear appli-

cations such as a source of neutrons, moderator and reflector. On the other hand, beryllium is a toxic material and its inhalation hazard can cause sensitization identified by lymphocyte proliferation testing (BeLPT or BeS), which is a few percentage (0–4%) of the exposed population, can further lead to chronic beryllium disease (CBD) which is an

J.C. Laul, PhD, REM, CHMM, and Rich Norman are affiliated with Safety Basis Division, Los Alamos National Laboratory, MS K489, P.O. Box 1663, Los Alamos, NM 87545, United States (Tel.: 505 665 9791; fax: 505 665 4599; e-mail: jclaul@lanl.gov).

incurable lung disease.⁷ However, the percent of CBD are far less than the percentage of BeS cases.

In an unlikely event of a seismic and fire, beryllium is released as an aerosol (<10 μm) into the atmosphere and plume is received down wind by a receptor (workers and public). It is very important to evaluate the consequences of the dose or concentration (mg/m^3) received by a receptor as a function of distance. One key parameter used in evaluating the consequence is the airborne release fraction (ARF) and respirable fraction (RF).

In the past, only ARF and RF values documented in DOE-HDBK-3010-94 by Mishima et al.³ are based on experimental observations for mainly plutonium (Pu) and uranium (U) in the various forms (liquid, solid, aggregates, powder, etc.) under various accident conditions (e.g., spill, fire, stress, explosion, etc.). These values are widely used for nuclear facilities at Department of Energy (DOE) sites to calculate estimated doses to workers and public. However, there is no such documentation to provide similar information for other toxic chemical material releases such as lithium, beryllium, titanium, sodium, cadmium, nickel, zirconium, mercury, etc., and their compounds during potential accidents. In the absence of such crucial information, most of the DOE sites use ARF/RF values from DOE-HDBK-3010-94,³ for Pu and U, analyzed under similar conditions of accident scenarios. Since the chemical properties of Pu and U and their compounds (e.g., toxicity and reactivity) may not be similar to other chemicals, such a selection of ARF/RF values may *not* be applicable and thus may prove to be unreliable. Some aspects of this concept applicable to other elements are discussed by Laul et al.⁸

Mishima et al.^{1,2} performed a comprehensive literature search that also included earlier literature search by Jordan,⁹ and proposed ARF/RF values for different forms (large coherent pieces, turnings/swarfs, chips/powder, and dust) under various accident conditions. These new ARF/RF values are different and lower by several orders of magnitude for explosion, fire and spill

than previously used. This implies a lower consequence exposure, an increase in threshold limit or lower facility hazard classification, lower operational cost, and better protection of the receptors. Laul¹⁰ used the new ARF/RF value for fire to justify in downgrading a High to Moderate hazard facility at Los Alamos National Laboratory (LANL). This was demonstrated through modeling to show that the public was protected at a distance suitable for being Moderate facility. The applications of new ARF/RF values are further extended by case studies of using 100 lbs chips/powder under various accident conditions (explosion, fire, and spill) in standard terrain (rural) and city terrain (urban) to assess the relative concentrations to a receptor at different distances, using EPIcode dispersion model that is also validated using manual calculations.

This paper focuses on the properties, ARF/RF, particle size fractions, facility hazard classification using ERPG/TEEL-3, -2, source term evaluation and accident analysis under various conditions (stability classes A to F), beryllium exposure guidelines and health effects (short and long term) in a potential accident, and protection of the workers and public.

BERYLLIUM PROPERTIES

Formula weight of beryllium is 9.02 with a metal density of $1.85 \text{ g}/\text{cm}^3$. Its melting point is 1278°C and boiling point is $2,467^\circ\text{C}$. Beryllium metal is hard, brittle and gray white. It is soluble in acids (except nitric acid) and alkalis. It is resistant to oxidation at ordinary temperatures but is susceptible to oxidation at higher temperature. It has high heat capacity and thermal conductivity. Beryllium in reaction with acid and alkalis produces beryllium hydride (BeH_2) and beryllium hydroxide $\text{Be}(\text{OH})_2$. On heating at $\geq 138^\circ\text{C}$, beryllium hydroxide converts to stable beryllium oxide (BeO) and its melting point is 2570°C and density is $3.05 \text{ g}/\text{cm}^3$.^{1,9}

Oxidation

Be metal particles have very thin coating film (1.2–8.1%), called “blue

oxide” film that is a protective layer (vapor-diffusion barrier), non-porous and tightly-adherent. Thermal expansion coefficient of Be metal is $11.4 \text{ ppm}/^\circ\text{C}$ and that of BeO is $9.0 \text{ ppm}/^\circ\text{C}$, which causes cracking of the “blue oxide” film on heating. Because of intrinsic expansion in the lattice, at elevated temperatures ($>800^\circ\text{C}$), vapors diffuse the protective layer and forms different physical characteristics of white “fluffy” material and leads to oxidation;



Oxidation mechanism of beryllium surfaces and films is explained by Adams and Hurd.¹¹ In a fire scenario, as the temperature rises the oxide layer disrupts and the oxidation proceeds rapidly. In addition, fire induced convection current may sweep up the fine metallic powder. However, this fine powder is also likely to get converted to oxide in a fire. *The oxidation largely depends on the temperature, duration of the fire, and the amount of material and its form.* Higher the temperature, higher is the degree of oxidation.

Fire temperature usually lies in the range of $700\text{--}900^\circ\text{C}$. Oxidation also takes place rapidly during ignition. The bulk powder, due to large surface area, ignites and is fully oxidized in a short time. There is a wide range of fire and ignition temperatures summarized,^{1,2,9} some in the range of $700\text{--}900^\circ\text{C}$ and higher. In some experimental studies, ignition temperatures are higher and close to the melting point of beryllium (e.g., Blumenthal and Santy¹²; Lindsay and Robinson¹³). Turnings/swarfs and large coherent metals have higher ignition temperatures than chips/powder, based on surface area consideration.^{1,9,12}

Complete oxidation is generally unlikely in explosion due to the very short time involved. It also depends on the amount of material and its form. A spill would not involve an oxidation. Materials, depending on the size, at elevated temperatures or close to ignition temperature will lead to oxidation. However, oxidation in a fire at $700\text{--}900^\circ\text{C}$ depends on the temperature, duration of fire, and the amount of material and its form. For example, powder is likely to undergo oxidation, while powder/

chips may not undergo complete oxidation. For conservatism, beryllium metal may be used to estimate consequences to the worker and the public.

ERPGs/TEELs FOR BERYLLIUM AND ITS COMPOUNDS AND THEIR CRITERIA

The Emergency Response Planning Guidelines (ERPGs)/Temporary Emergency Exposure Limits (TEELs) are commonly used to assess the severity of exposure from beryllium and compound to a receptor, listed in Table 1. The ERPGs/TEELs with increasing severity are defined as follows.^{1,2,14}

ERPG/TEEL-1: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

ERPG/TEEL-2: The maximum airborne concentration, below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective actions.

ERPG/TEEL-3 is the "maximum airborne concentration, below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening health effects".

Exposure Criteria

Based on the American Industrial Hygiene Association (AIHA) documentation of 1998,¹⁵ beryllium ERPG values were based on animals (rat, guinea pig, mouse) toxicology data at LD₅₀ (oral toxicity, mg Be/kg) and LC₅₀ (inhalation toxicity, mg Be/m³) using beryllium compounds of fluoride, chloride, phosphate, sulfate, and oxyfluoride for 4-hr duration. Beryllium compounds can cause ulcer of the eye. Beryllium sulfate produced skin granulomas and sensitization in guinea pigs. Sensitization can occur with skin absorption by beryllium compounds.

Table 1. ERPGs/TEELs Values for Beryllium and its Compounds^a

Compound	ERPG/TEEL-1 (mg/m ³)	ERPG/TEEL-2 (mg/m ³)	ERPG/TEEL-3 (mg/m ³)
Beryllium metal, Be	0.005	0.025	0.1
Beryllium hydroxide, Be(OH) ₂	0.025	0.25	20
Beryllium oxide, BeO	0.0125	1.25	10 ^b
Ratio of BeO/Be	2.5	50	100

^a 1 mg/m³ = 2.72 ppm.

^b On oxidation, Be is converted to BeO, which has 100 times more threshold value than Be metal (10 vs. 0.1 mg/m³), based on the comparison of ERPG-3/TEEL-3 values. Thus, in a major fire scenario if Be is oxidized to BeO then it is lot less hazard to a receptor on a short term exposure. For long term (chronic) exposure, both Be metal and BeO can lead to CBD, however, their relative degree of hazards is not known.

In terms of human experience, beryllium exposure is largely through inhalation, although absorption through skin can also contribute to the total absorbed dose. The beryllium exposure can cause acute disease due to high exposure (e.g., ERPG-3 level). BeS can follow either acute or chronic exposure to Be and an interstitial lung disorder called CBD or berylliosis can develop after BeS.

Current Occupational Exposure Guidelines

The American Conference of Government Industrial Hygienists (ACGIH)⁵ threshold limit value (TLV) for beryllium on an 8-hr TWA is 2 µg/m³. However, 10 CFR 850 Rule, *Chronic Beryllium Disease Prevention Program; Final Rule*, Section 850.23,⁶ requires a protective action level at 0.2 µg/m³ (air, 8-hr TWA exposure) for a worker as measured in the worker's breathing zone by personal monitoring. This action level is intended to further mitigate or prevent any health effects and CBD. The exposure dose is 62 times lower than the ERPG-3 exposure of 100 µg/m³.

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) is also 2 µg/m³ as an 8-hr TWA. The 30-min short term exposure limit (STEL) is 5 µg/m³; the ceiling limit is 25 µg/m³ (ERPG-2). The OSHA 8-hr PEL is intended to prevent CBD; the ceiling level is intended to prevent acute symptoms of berylliosis.

FACILITY CHEMICAL HAZARD CLASSIFICATION CRITERIA

Some DOE sites use inventory criteria and some sites use consequence criteria for facility chemical hazard classification (CHC).¹⁴ For a beryllium facility, DOE sites usually consequence criteria of ERPG-3 or -2/TEEL-3 or -2 depending on the distance close to the site boundary (public). (For short site boundary, ERPG-2/TEEL-2 is usually used.)

A facility is a High hazard if the anticipated consequence exceeds the ERPG/TEEL-3, -2 at the site boundary (public effect); Moderate hazard if the anticipated consequence exceeds the ERPG/TEEL-3, -2 at 100 m for the collocated workers or noninvolved workers; and Low hazard if the anticipated consequence exceeds the ERPG/TEEL-3, -2 for the involved worker, shown in Table 2.

For chemical hazard classification purposes, ERPG/TEEL values relate to an acute effect, which for beryllium is pneumonia-like and curable. Chronic exposure to a Be releases may result in CBD.

AIRBORNE RELEASE FRACTION/RESPIRABLE FRACTION

Laul et al.⁸ provided some guidance on the use of ARF/RF for toxic chemicals based on DOE-HDBK-3010-94.³ Basically, if the element's physical and chemical properties are not altered by the accident stresses, particulate toxic che-

Table 2. Facility Chemical Hazard Characterization Criteria^a

Category	Criteria	Distance
High	>ERPG-3, -2/TEEL-3, -2	Site boundary (public)
Moderate	>ERPG-3, -2/TEEL-3, -2	100 m ^a (collocated worker) or noninvolved workers
Low	>ERPG-3, -2/TEEL-3, -2	Involved worker

^a Some facilities may have noninvolved workers less than or more than 100 m.

mical materials generally behave similarly to the surrogate materials used in the experimental studies of Pu and U in DOE-HDBK-3010-94 values,³ then the selection of ARF/RF values are generally appropriate. Factors such as density, particle size distribution, and deposition play an important role in the evaluation of the ARF/RF values.

Mishima et al.^{1,2} wrote a comprehensive report on “*Beryllium Metal Airborne Release Fractions and Respirable Fractions for DOE Facility Accidents Analyses*”, which provides literature review on the physical and chemical properties of beryllium metal and its oxide, oxidation and ignition of beryllium metal, and accidents involving beryllium releases. Most importantly, the report provides the size fractions information (<8.0 μm to <100 μm in 12 increments) that was used to calculate the ARF/RF values for different forms of beryllium (large coherent metal, powder/chips, turnings/swarfs, and dust layer) under various accident conditions listed in Table 3. The ARF/RF values in

Table 3 are supported by experimental data.^{1,2} Powder/chips consist of spherical/cubic shapes with a d_G <1.27 cm.

BERYLLIUM METAL PARTICLE SIZE DISTRIBUTION

The particle distribution size of the material plays an important role in the correlation of the surface to volume ratio and size and in the ARF/RF. Beryllium metal powder is frequently received from the vendor, Brush-Wellman. The Particle Size Distribution of the beryllium powder in Figure 1 is typically similar every time the powder is received from the vendor. The mass fraction in each size bin shows that the largest mass fraction in the bin centered at d_G 65- μm (d_{AED} ~81.6- μm). Figure 2 shows the Cumulative Mass Fraction versus Particle diameter. The mass median diameter is d_G ~50- μm (d_{AED} 68- μm).

The less than 10 μm fraction is about 3%. The surface to volume ratio gen-

erally decreases with increasing diameter of the piece. Thus, the ARF and RF values for the various beryllium forms in Table 3 are based upon the surface to volume ratio and size.

SOURCE TERM AND CONSEQUENCE EVALUATION

Source term (ST) estimation is defined by use of a five factor formula, shown below, is taken from DOE-HDBK-3010-94.^{3,8}

$$ST = MAR \times ARF \times RF \times DR \times LPF \quad (1)$$

where MAR represents material at risk available for release (typically in mg); ARF, airborne release fraction suspended in air as an aerosol and available for transport to a nearby onsite receptor (minimum 100 m from the release point as recommended for Gaussian dispersion) or offsite public; RF, respirable fraction: the fraction of airborne particles that can be transported through air and inhaled into the human respiratory system; commonly assumed to include particles $\leq 10\text{-}\mu\text{m}$; aerodynamic equivalent diameter (AED); DR, damage ratio of the total MAR that could be impacted by the accident generated conditions. For conservative value, DR is 1; LPF, leak-path factor: the fraction of airborne material transported from confinement deposition or filtration mechan-

Table 3. Summary of ARF/RF Values for Encased Be Metal^a

Condition	Airborne Release Fraction (ARF)/Respirable Fraction (RF) Values			
	Large, Coherent Items	Powder/Chips	Turnings/Swarfs	Dust Layer
Explosion, detonation	1E-1/0.3	1E-2	1E-2	4E-1
Explosion, deflagration	<1E-6	1E-2	1E-2	4E-1
Explosive release [e]	<1E-6	1E-3	1E-2	1E-1/0.7
Fire, Be heated	3E-6	1.5E-5	2E-4	3E-4
Fire, Be ignited		4E-1	4E-1	4E-1
Fire, packaged combustible waste, waste ignited, Be heated	–	2E-5	–	3E-4
Fire, packaged combustible waste, waste and Be ignited	–	–	–	4E-1
Free-fall spill	<1E-6	<1E-6	<1E-6	2E-3/0.3
Crush-impact	<1E-6	<1E-6	<1E-6	1E-3/0.3
Shock-vibration	<1E-6	<1E-6	<1E-6	1E-3/0.3
Resuspension	<1E-6	<1E-6	<1E-6	4E-5/hr (ARR)

^a Taken from Mishima et al.^{1,2} See references 1, 2 for footnote explanations. Oxidation largely depends on the fire temperature, duration of the fire, and the amount of material involved and its form.

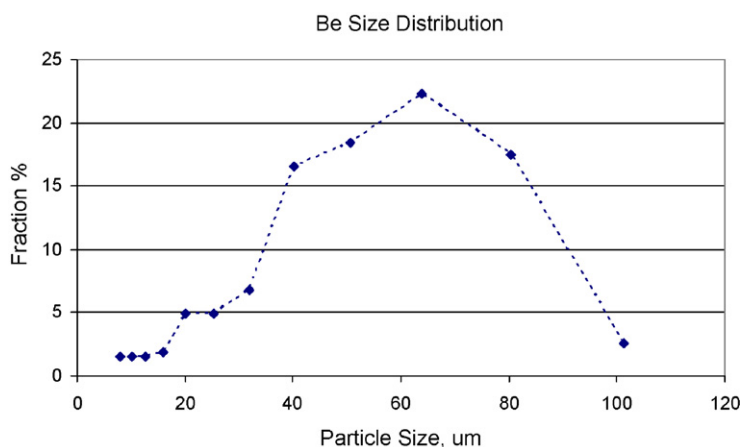


Figure 1. Particle size distribution of Brush-Wellman, 205 Production Powder, size vs. mass fraction (taken from Ref. 1).

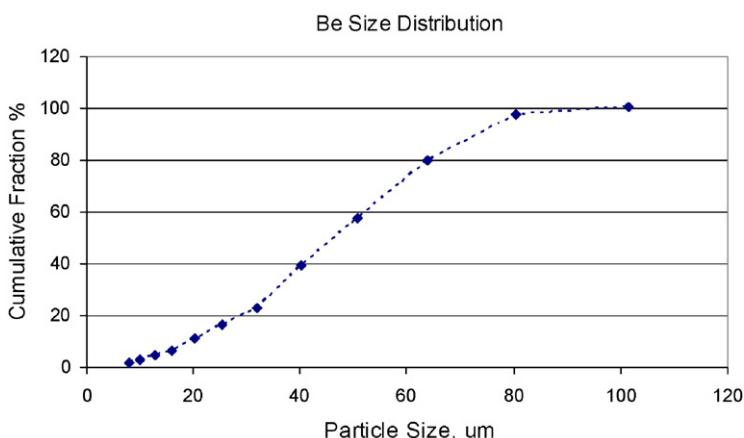


Figure 2. Cumulative mass fraction vs. particle diameter. The mass median diameter is $d_G \sim 50\text{-}\mu\text{m}$ ($d_{AED} 68\text{-}\mu\text{m}$) (taken from Ref. 1).

ism (e.g., fraction of material passing through a HEPA filter); for breach of confinement, conservative LPF is 1.

Release concentration estimate to a receptor location is defined by the use of the following formula.

$$\text{concentration (mg/m}^3\text{)} = \frac{\chi/Q \times ST}{T} \quad (2)$$

where ST (mg) is the source term of material released (per sampling time period chemical analyses), χ/Q (s/m³) the atmospheric dispersion coefficient at an evaluated receptor location that typically represents the 95th percentile value from statistical treatment of meteorological data (as a default alternative, the χ/Q value may be based on atmospheric conditions

of stability class F with 1–2 m/s wind speed, which is conservative), T (s) the release duration, typically 15 min.

Knowing χ/Q , ST, and T , concentration (mg/m³) at the receptor distance can be calculated and then compared with the ERPG/TEEL-1, -2, -3 values (mg/m³ or ppm). Typical computer code models used for performing consequence analysis from chemical releases are Emergency Prediction Information Code (EPIcode)¹⁶ and Areal Locations of Hazardous Atmospheres (ALOHA)¹⁷. These calculations can be verified manually.

As a conservative estimate, if RF, DR, and LPF values are unity, then

$$ST = MAR \times ARF \quad (3)$$

MAR is usually a known fixed quantity; therefore, the ARF plays an important role in determining the source term and the estimated released concentration. Thus, an accurate or defensible determination of the ARF value is important in calculating quantitative consequence from a postulated accident. Another very important parameter is χ/Q (s/m³) that can vary significantly (1–3 orders of magnitude) depending on the weather conditions (stability class A to F). Thus its accurate determination is also crucial in calculating quantitative consequence. Computer models typically use a centerline Gaussian dispersion plume model, which is discussed as follows.

ATMOSPHERIC DISPERSION MODEL

A typical dispersion model uses a Gaussian centerline approach to model the transport of particulates in an atmosphere.¹⁸ The concentration (mg/m³) to a receptor depends on a distance, atmospheric stability (A to F class), wind speed, deposition velocity, and release height. To calculate concentration along the plume centerline at ground level from a ground level release ($y = 0$, $z = 0$, $H = 0$), the equation is taken from Turner, which is as follows.¹⁸

$$\chi(x, 0, 0; 0) = \frac{Q}{\pi u \sigma_y(x) \sigma_z(x, z_0)} \quad (4)$$

where χ is the air pollutant concentration in mass per volume, g/m³ or mg/m³; Q pollutant emission rate in mass per time, g/sec or mg/sec (equivalent to ST/T); u wind speed at the point of release, m/sec; $\sigma_y(x)$ standard deviation of horizontal crosswind plume spread (m) at the downwind distance x ; $\sigma_z(x, z_0)$ standard deviation of the vertical plume (m) direction, at the downwind distance x ; π 3.142.

Rearranging Eq. (4) yields

$$\frac{\chi}{Q}(x) = \frac{1}{\pi u \sigma_y(x) \sigma_z(x, z_0)} \quad (5)$$

The standard deviations of the plume spread over flat terrain covered by grass (surface roughness length (z_0))

of 3 cm) are calculated using the Tadmor–Gur equations:

$$\sigma_y(x) = a_i x^{b_i} \quad (6)$$

$$\sigma_z(x, 3 \text{ cm}) = c_i x^{d_i} \quad (7)$$

The dispersion factors for a distance of 100 m with a stability class of F and a wind speed of 1.5 m/sec taken from Tadmor–Gur constants are:

a_i	b_i	c_i	d_i
0.0722	0.9031	0.2	0.602

$$\sigma_y(100 \text{ m}) = a_i x^{b_i} = 0.0722 (100)^{0.9031} = 4.62 \text{ m}$$

$$\sigma_z(100 \text{ m}) = c_i x^{d_i} = 0.2 (100)^{0.602} = 3.20 \text{ m}$$

From Eq. (5):

$$\begin{aligned} \frac{\chi}{Q}(100 \text{ m}) &= \frac{1}{\pi u \sigma_y(x) \sigma_z(x)} \\ &= \frac{1}{\pi (1.5 \text{ m/s}) (4.62 \text{ m}) (3.20 \text{ m})} \\ &= 0.01435 \frac{\text{sec}}{\text{m}^3} \text{ or } 1.43\text{E-}2 \text{ sec/m}^3 \end{aligned}$$

$$\begin{aligned} \text{concentration (mg/m}^3\text{)} \\ &= \frac{[\chi/Q \times \text{MAR} \times \text{ARF}]}{T} \quad (8) \end{aligned}$$

$$\text{MAR} = \frac{\text{concentration (mg/m}^3\text{)} \times T}{\chi/Q \times \text{ARF}} \quad (9)$$

For beryllium, parameters are as follows: $\chi = 0.1 \text{ mg/m}^3$ or 10^{-4} g/m^3 (ERPG/TEEL-3 value); $T = 15 \text{ min}$ or 900 s release time; $\chi/Q = 1.43\text{E-}2 \text{ s/m}^3$; $\text{ARF} = 0.001$ or $1\text{E-}3$ for solid.

Inserting these parameters, MAR is 13.9 lbs for beryllium solid. EPIcode also yields a MAR value of 13.9 lbs with a χ/Q value of $1.38\text{E-}2 \text{ sec/m}^3$; however, it uses a wind speed height of 2 m (default value in the code) and 2 m receptor height. If the receptor height is 1.5 m, then MAR is 10 lbs with a χ/Q value of $1.99\text{E-}2 \text{ s/m}^3$. Manual calculations uses zero wind speed height and zero receptor height, which explains some of the differences. EPIcode has a built in equation as a function of wind speed height and receptor height. Overall, EPIcode is a

Table 4. Powder/Chips Combined ARF/RF: (97% Powder/Chips + 3% Dust (<10 μm))

Event	Combined ARF/RF	Oxidation ^a
Explosion: detonation/deflagration	2.2E-2	No
Explosive release	3.1E-3	No
Fire, Be heated	2.35E-5	Yes/no
Fire, Be ignited	4.0E-1	Yes
Fire, combustible waste	2.35E-5	Yes
Free-fall spill	1.8E-5	No

^a Oxidation largely depends on the fire temperature, duration of the fire, and the amount of material involved and its form.

reliable code and can be verified manually using equations provided in manual. EPIcode performs calculations for term release, fire, explosive release, continuous release, and liquid spill.

CONSEQUENCE CALCULATIONS USING DISPERSION MODEL (EPICODE)

Both EPIcode¹⁶ and ALOHA¹⁷ are commonly used computer codes¹⁹ for chemical dispersion consequence models. Both models have their manuals that describe their features and recommend parameters for calculations.^{20,21} Since EPIcode has attractive features of using deposition velocity, displaying χ/Q (s/m^3) value, and providing results for various distances in printout, while ALOHA does not, EPIcode window version 7.0 (September 2003)¹⁶ is used here to calculate consequences.

Test Cases Using Powder/Chips

A beryllium facility is assumed to have an inventory of 100 lbs powder/chips stored in a room. Site boundary distance for this facility is assumed at 1,000 m (1 km). The ARF/RF values for powder/chips shown in Table 3 and particle size distribution being 3% for <10 μm fraction, the combined ARF/RF is a combination of 97% powder/chips and 3% dust (<10 μm), shown in Table 4.

Parameters Used

The recommended parameters or assumptions²⁰ used for calculations are as follows.

- Release type: (a) explosive release; (b) term release; (c) fire (heated, ignited, combustible); (d) continuous release (spill). Term release is highly conservative relative to a fire that involves lofting. Release is specified for specific duration (time).
- Stability class: F, which is stable and most conservative class among A to F classes.
- Surface wind speed: 1–2 m/s is assigned for F stability. 1.5 m/s at 10 m height is recommended and used (DOE-EH-4.2.1.3-EPIcode Guidance).²⁰
- Deposition velocity of 0 cm/sec is used as conservative; however, DOE-EH-4.2.1.3-EPIcode Guidance recommends 0.3 cm/s.²⁰ 0.3 cm/s is used although one case uses 0 cm/sec for comparison.
- Release effective height: 0 m, which is ground level release.
- Receptor height 1.5 m. This is normally chest height.
- Release time (RT) and sampling time (ST) of typically 15 min each is recommended as the time weighted average (TWA) to compare with the ERPG/TEEL values, although the ERPGs/TEELs are defined as exposure up to one hour.^{22,23}
- RF = 1.0, because ERPG/TEEL-3 assumes total concentration exposure to a receptor.
- Terrain Standard: Open country which is a conservative; City terrain is urban or metropolitan
- Downwind X-meter: Plume centerline, Y-meter 0.

Results are shown in Table 5 (standard terrain) and Table 6 (city terrain).

Table 5. Beryllium Powder/Chips Concentrations (Standard Terrain) vs. Distances, Using EPIcode

	Explosion: Detonation/Deflagration		Fire: Be Heated				Fire: Be Ignited		Fire: Combustible Waste, Be Heated	Spill: Free Fall
MAR, powder/chips	100 lbs		100 lbs		100 lbs		100 lbs		100 lbs	100 lbs
ARF ^a	2.2E-2		2.35E-5		2.35E-5		4.0E-1		2.35E-5	1.8E-5
Source term	2.2 lb		2.35E-3 lb		2.35E-3 lb		40 lbs		2.35E-3 lb	1.8E-3 lb
Model used	Explosive release		Term release		Fire 1 MW internal	Fire 1 MW external	Term release	Fire 5 MW external	Fire 0.5 MW in drum	Continuous release
	2.0 lbs TNT	10 lbs TNT			Radius 1 m, fire ht 2 m	Radius 1 m, fire ht 2 m		Radius 1 m, fire ht 2 m	Radius 1 m, fire ht 2 m	Rate 50.3 g/sec
Deposition velocity	0.3 cm/s	0.3 cm/s	0 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/sec	0.3 cm/s
Comment	Cloud top 90 m	Cloud top 135 m			Cloud top 4 m	Release ht 40 m		Release ht 62 m	Release ht 33 m	
Release time (RT), Sampling time (S'T)	RT = instantaneous, S'T = 15 min		RT 15 min, S'T 15 min		RT 15 min, S'T 15 min		RT 15 min, S'T 15 min		RT 15 min, S'T 15 min	RT 15 min, S'T 15 min
Parameters used	Surface wind speed 1.5 m/sec (<i>h</i> = 10 m); stability class F, effective release ht 0 m; Receptor ht 1.5 m (ground level); RF = 1.0; Gaussian distribution; terrain standard (rural, open country); downwind X-meter, Y-meter 0 (plume centerline)									
Concentration	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³
30 X-meter	7.3	2.3	6.8E-3	5.2E-3	1.8E-2	0	88	0	0	4.0E-3
100 m	5.6	1.8	5.7E-2	3.2E-2	1.5E-2	0	550	0	0	2.5E-2
200 m	4.3	1.5	2.1E-2	1.0E-2	7.9E-3	1.2E-29	170	0	6.8E-21	7.6E-3
400 m	2.4	1.0	6.1E-3	2.4E-3	2.9E-3	2.2E-12	41	2.4E-21	1.6E-9	1.9E-3
600 m	1.1	0.70	2.9E-3	1.0E-3	1.4E-3	1.4E-8	18	2.9E-11	4.6E-7	8.0E-4
800 m	0.67	0.44	1.7E-3	5.8E-4	8.3E-4	3.7E-7	9.8	2.2E-7	3.6E-6	4.4E-4
1,000 m	0.49	0.25	1.2E-3	3.7E-4	5.5E-4	1.7E-6	6.3	1.7E-5	9.1E-6	2.8E-4
1,500 m	0.26	0.14	6.0E-4	1.6E-4	2.5E-4	7.1E-6	2.7	1.6E-3	1.9E-5	1.2E-4
2,000 m	0.17	0.090	3.8E-4	9.2E-5	1.4E-4	1.0E-5	1.6	8.5E-3	2.1E-5	7.0E-5
χ/ <i>Q</i> (s/m ³), 1,000 m (site boundary),	4.9E-7	2.5E-7	1.0E-3	3.1E-4	4.6E-4	1.45E-6	3.1E-4	8.5E-10	7.7E-6	3.1E-4
ERPG-3 (mg/m ³)	0.10	0.10	0.10/10	0.10/10	0.10/10	0.10/10	10	10	10	0.10
ERPG-2 (mg/m ³)	0.025	0.025	0.025/1.25	0.025/1.25	0.025/1.25	0.025/1.25	1.25	1.25	1.25	0.025
Oxidation ^b	No	No	No/yes	No/yes	No/yes	No/yes	Yes	Yes	Yes	No

^aIt is 97% powder/chips + 3% dust (<10 μ m); 1 mg/m³ = 2.72 ppm. ^bOxidation largely depends on the temperature, duration of fire, and the amount of material and its form.

Table 6. Beryllium Powder/Chips Concentrations (City Terrain) vs. Distances, Using EPIcode

	Explosion: Detonation/Deflagra- tion		Fire: Be heated				Fire: Be ignited		Fire: Combustible waste, Be heated	Spill: Free fall
MAR, powder/chips	100 lbs		100 lbs		100 lbs		100 lbs		100 lbs	100 lbs
ARF ^a	2.2E-2		2.35E-5		2.35E-5		4.0E-1		2.35E-5	1.8E-5
Source term	2.2 lbs		2.35E-3 lbs		2.35E-3 lbs		40 lbs		2.35E-3 lbs	1.8E-3 lbs
Model used	Explosive release		Term release		Fire 1 MW internal	Fire 1 MW external	Term release	Fire 5 MW external	Fire 0.5 MW in drum	Continuous release
	2.0 lbs TNT	10 lbs TNT			Radius 1 m, fire ht 2 m	Radius 1 m, fire ht 2 m		Radius 1 m fire ht 2 m	Radius 1 m, fire ht 2 m	Rate 50.3 g/sec
Deposition velocity	0.3 cm/s	0.3 cm/s	0 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s	0.3 cm/s
Comment	Cloud top 90 m	Cloud top 135 m			Cloud top 4 m	Release ht 39 m		Release ht 61 m	Release ht 32 m	
Release time (RT), Sampling time (S'T)	RT = instantaneous, S'T = 15 min		RT = 15 min, S'T = 15 min		RT = 15 min, S'T = 15 min		RT = 15 min, S'T = 15 min		RT = 15 min, S'T = 15 min	RT = 15 min, S'T = 15 min
Parameters used	Surface wind speed 1.5 m/sec (<i>h</i> = 10 m); stability class F, effective release ht 0 m; receptor ht 1.5 m (ground level); RF = 1.0; Gaussian distribution; terrain city (urban, metropolitan area); downwind X-meter, Y-meter 0 (plume centerline)									
Concentration	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³	mg/m ³
30 X-meter	6.7	2.1	6.4E-3	6.1E-2	2.1E-2	0	1.0E+3	0	7.5E-29	4.7E-2
100 m	4.3	1.6	7.4E-3	6.6E-3	4.3E-3	7.6E-9	1.1E+2	2.8E-12	3.8E-7	5.1E-3
200 m	1.9	1.0	2.0E-3	1.7E-3	1.3E-3	8.5E-6	30	5.6E-4	3.0E-5	1.3E-3
400 m	0.58	0.31	5.9E-4	4.8E-4	3.7E-4	3.0E-5	8.2	7.2E-2	4.8E-5	3.7E-4
600 m	0.31	0.18	2.9E-4	2.4E-4	1.8E-4	2.5E-5	4.0	0.14	3.5E-5	1.8E-4
800 m	0.19	0.12	1.8E-4	1.5E-4	1.1E-4	2.0E-5	2.5	0.14	2.5E-5	1.1E-4
1,000 m	0.13	0.086	1.3E-4	1.0E-4	7.9E-5	1.5E-5	1.7	0.13	1.9E-5	7.8E-5
1,500 m	0.059	0.045	7.0E-5	5.4E-5	4.2E-5	9.2E-6	0.92	0.10	1.1E-5	4.1E-5
2,000 m	0.034	0.028	4.6E-5	3.5E-5	2.8E-5	6.4E-6	0.60	0.071	7.3E-6	2.7E-5
χ/Q (s/m ³), 1,000 m (site boundary)	1.3E-7	8.6E-8	1.1E-4	8.6E-5	6.7E-5	1.2E-5	8.6E-5	6.5E-6	1.6E-5	8.6E-5
ERPG-3 (mg/m ³)	0.10	0.10	0.10/10	0.10/10	0.10/10	0.10/10	10	10	10	0.10
ERPG-2 (mg/m ³)	0.025	0.025	0.025/1.25	0.025/1.25	0.025/1.25	0.025/1.25	1.25	1.25	1.25	0.025
Oxidation ^b	No	No	No/yes	No/yes	No/yes	No/yes	Yes	Yes	Yes	No

^aIt is 97% powder/chips + 3% dust (<10 μ m); 1 mg/m³ = 2.72 ppm. ^bOxidation largely depends on the temperature, duration of fire, and the amount of material and its form.

RESULTS AND DISCUSSION

Tables 5 and 6 provide summary of Be concentration (mg/m^3) versus distances for both standard terrain and city terrain. Value at 30 m has large uncertainty, although this value is still useful. Standard terrain being rural and open country has less resistance, whereas, city terrain being urban or metropolitan has trees and buildings and thus more resistance. Thus, standard terrain will always have higher concentrations than city terrain. The ERPG-3 value is used here to evaluate consequence. Discussions on each release type scenario are as follows.

Explosion

Using an ARF of $2.2\text{E}-2$, ST is 2.2 lbs. Two values of explosion scenarios with 2 lbs TNT and 10 lbs TNT are chosen to illustrate the relative comparison of the Be concentration profiles as a function of distance for standard terrain and city terrain. Four plumes of Be concentration profiles are shown in Figure 3. For standard terrain, highest Be concentration is $7.3 \text{ mg}/\text{m}^3$ at 30 m and gradually falls to $0.49 \text{ mg}/\text{m}^3$ at 1,000 m (1 km), by a reduction factor of 15. Plume reaches a cloud top (height) of 90 m. With 10 lbs TNT, Be concentration is $2.3 \text{ mg}/\text{m}^3$ at 30 m and falls to $0.25 \text{ mg}/\text{m}^3$ at 1 km, by a reduction factor of ~ 10 . Plume reaches a cloud plume top (ht) of 135 m. This comparison indicates that with increasing TNT-lb, cloud top height increases, while the Be concentration decreases. Likewise, with less TNT-lb (1-lb TNT), Be concentration will increase while the cloud top height decrease. This is due to plume dispersion phenomenon, which is also reflected in the lower corresponding χ/Q (s/m^3) value at 1 km.

In city terrain, for 2 lbs TNT, Be concentrations are $6.7 \text{ mg}/\text{m}^3$ at 30 m and $0.13 \text{ mg}/\text{m}^3$ at 1 km, with a reduction factor of 52. With increasing distance, Be concentrations decrease more relative to the standard terrain. With 10 lbs TNT, concentration is $2.1 \text{ mg}/\text{m}^3$ at 30 m and falls to $0.086 \text{ mg}/\text{m}^3$ at 1 km, with a reduction factor of 24. However, the cloud top is the same 90 m for 2 lbs TNT and 135 m for 10 lbs TNT. Since the explosion interval

is very short, ERPG-3 for Be as metal is used, which exceeds in three cases except for City at 10 lbs TNT case.

Fire: Be Heated

With an ARF of $2.35\text{E}-5$, ST is $2.35\text{E}-3$ lbs. Dispersion analysis is modeled in two ways with four scenarios. Term release is straight line Gaussian distribution and is conservative. One scenario assumes no deposition velocity (no fall out of particulates as plume travels) and second scenario assumes $0.3 \text{ cm}/\text{s}$ deposition velocity (default value in code), which is a realistic approach. Two 1 MW ($2.39\text{E}+5 \text{ cal}/\text{s}$) fires are considered: internal and external fire. In both cases, 1-m radius and 2-m fire height are assumed. In internal fire, 4-m cloud top height (room ceiling height) is assumed. Roof ceiling is not breached

and plume by inversion mechanism escapes through windows or ventilation and gets into the environment. External fire is an open parking lot scenario and the model calculates the plume height. Plume concentration profiles of two term scenarios and internal fire are shown in Figure 4.

Term release shows initial rise from 30 m to 100 m and gradually decrease in concentration (mg/m^3) with distance. As expected, term release with zero deposition velocity shows higher Be concentration than term release with $0.3 \text{ cm}/\text{sec}$ deposition velocity for standard terrain (Table 5). The concentration ratio of 100 m/1 km is 47 for zero deposition velocity as compared to the concentration of 86 for $0.3 \text{ cm}/\text{sec}$ deposition. This concentration ratio is expected to increase with distance, due to fall out of more large

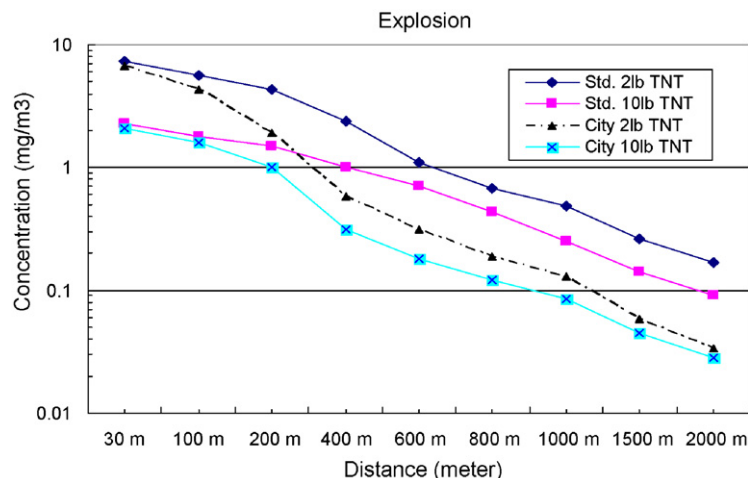


Figure 3. Explosion: concentration profiles (mg/m^3) for standard and city terrain.

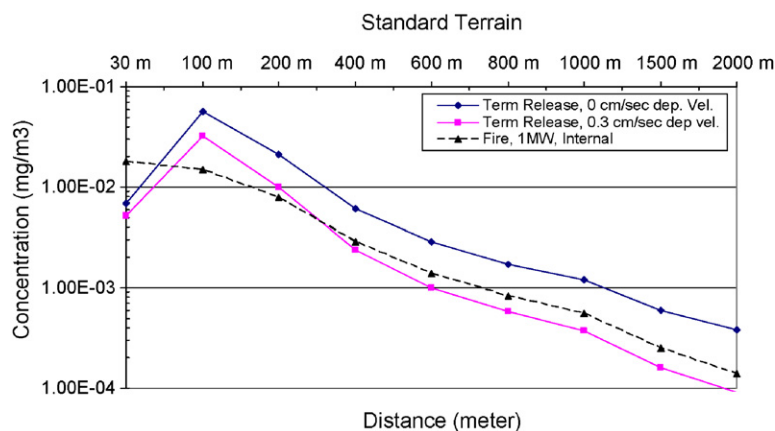


Figure 4. Fire: Be heated; concentration profiles (mg/m^3) for standard terrain.

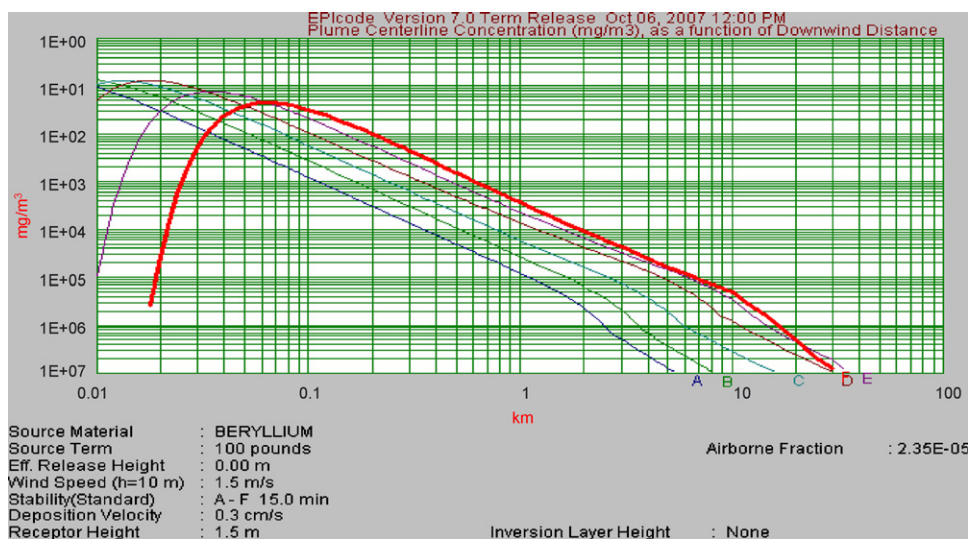


Figure 5. Term release: concentration profiles (mg/m³) for A to F stability classes.

particulates with distance. The internal fire plume apparently shows virtually no lofting and follows a typical term release profile similar to 0.3 cm/sec profile (Figure 4).

Figure 5 shows a typical term release profile for all stability classes (A to F) on a log-log plot. Based on meteorological consideration, stability class A is least stable, whereas class F is most stable. By comparison of concentration profiles, it is obvious that stability class F yields the most conservative results.

External fire

External fire profile is shown in Figure 6. Plume reaches release height of 40 m. There is considerable lofting of plume, where the initial concentrations are extremely low, and the plume rises from 500 m to 2 to 4 km and then gradually decreases in concentration. Due to large plume dispersions, χ/Q values are very low (e.g., $1.45E-6$ s/m³ at 1000 m) and subsequently the concentrations are also very low with increasing distance. Figure 6 illustrates this point on a log-log plot. It is to note

however that the concentrations are not conservative in F stability class. By comparison, class D (4.5 m/s) starts at an earlier distance (0.1 km) and yields conservative results than F and other classes. Thus, in external fire, class D is preferred over class F. The similar profile trends are also observed for the city terrain except the observed concentrations in Table 6 are considerably higher than for standard terrain.

In the fire heating scenario, Be can be partly or completely oxidized to BeO. The oxidation largely depends

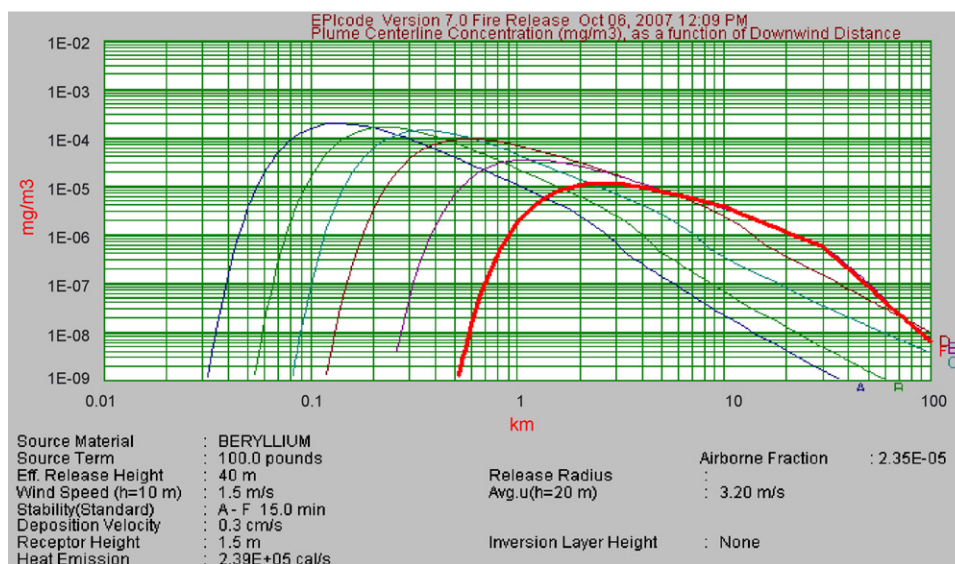


Figure 6. Fire release (lofting) profiles for A to F classes. Class D is more conservative than class F.

on the temperature, duration of fire, and the amount of material and its form. For example, finer particles are likely to be readily oxidized relative to chips. Thus ERPG-3 for Be metal and oxide are applicable depending on the conditions.

Facility hazard classification

For facility chemical hazard classification, fire has higher ARF/RF value than spill (Table 4) and thus fire ARF/RF is used as bounding scenario with term release (no lofting) as being conservative. Using standard terrain, concentration with 0 cm/sec deposition velocity is $57 \mu\text{g}/\text{m}^3$ at 100 m and $1.2 \mu\text{g}/\text{m}^3$ at 1 km. The ERPG-3 for Be metal (conservative) is $100 \mu\text{g}/\text{m}^3$. By comparison and using guideline in Table 2, this facility is classified as a *Low* hazard facility, because the concentrations are below the 100 m and 1 km (site boundary) distances. If ERPG-2 ($25 \mu\text{g}/\text{m}^3$) criteria is to be used, then this facility is a *Moderate* hazard facility. If term release with 0.3 cm/sec deposition velocity value of $32 \mu\text{g}/\text{m}^3$ at 100 m is used, the conclusion is same as being Moderate hazard facility.

Fire: Be Ignited

In ignition scenario, ARF is quite high 0.40, which yields a ST of 40 lbs with 100 lbs MAR. Two scenarios are evaluated; term release and external fire at 5 MW ($1.19\text{E}+6$ cal/sec) with release radius 1 m and fire height 2 m. With 40 lbs ST, release concentrations are much higher in both scenarios. In the case of term release, concentrations

are $88 (\text{mg}/\text{m}^3)$ at 30 m, $550 (\text{mg}/\text{m}^3)$ at 100 m and $6.3 (\text{mg}/\text{m}^3)$ at 1 km, which yields a value of 87 for 100 m/1 km ratio and a value of 14 for 30 m/1 km ratio. This indicates somewhat initial lofting for standard terrain. However, for city terrain, concentrations are $1,000 (\text{mg}/\text{m}^3)$ at 30 m, $110 \text{ mg}/\text{m}^3$ at 100 m and $1.7 \text{ mg}/\text{m}^3$ at 1 km, which yields a value of 64 for 100 m/1 km ratio and a value of 589 for 30 m/1 km ratio. This indicates apparently no lofting for city terrain, which may be due to presence of trees and buildings (resistance). The same trend was also noted in the Fire-Be heated (Tables 5 and 6).

5 MW fire yields significantly higher lofting in standard terrain as compared to city terrain. In standard terrain, plume initially starts at 400 m and rises to about 4 km and then starts declining in concentration, whereas in city environment, the plume starts at 0.1 km to 1 km and starts declining in concentration with distance. The release top height is 61 m in both cases.

In ignition, the expected temperatures are high $>1,000^\circ\text{C}$, where the outer coating (blue film) of Be metal fractures and Be gets readily oxidized to BeO. The ERPG-3 of BeO is used for consequence evaluation at the receptor distances.

Fire Combustible Waste: Be Heated

The Be ST of $2.35\text{E}-3$ lb is the same as used for Fire-Be heated case. Thus, the term release results with zero and 0.3 cm/sec deposition velocity are the same for both standard and city

terrains (Tables 5 and 6). Only small confined fire of 0.50 MW ($1.2\text{E}+5$ cal/s) in a 55-gallons drum is considered for evaluation. Other assumed parameters of radius 1 m, fire height 2 m and 0.3 cm deposition velocity are the same. In standard terrain, plume initially starts at 400 m and increases to 2 km and then starts declining with distance. In city terrain, plume starts at 30 m and increases up to 400 m and declines with distance, and follows a typical fire pattern. The release plume height is 33 m in both cases.

Although it is small fire (0.5 MW), because of the combustible material present inside the drum, the internal fire temperature can be high ($\sim 1,000^\circ\text{C}$ or higher), where Be is readily oxidized to BeO. The ERPG-3 of BeO applies in this case.

Spill: Free Fall

Continuous release model is used for spill. Based on 15 min release time of 100 lbs powder/chips, release rate of 50.3 g/s is used. The concentration profiles are similar and follow the term release pattern with 0.3 cm/s deposition velocity. As in other term releases cases, standard terrain shows somewhat initial lofting, while city terrain shows no lofting. ERPG-3 for Be metal applies for consequence evaluation.

PROTECTION OF PUBLIC AND WORKERS

The Environmental Protection Agency (EPA) imposes a National Emission

Table 7. Comparison of Be Concentrations with EPA Limit

Scenario		30 days TWA	15 min TWA	Comment
EPA emission limit	Be release	$0.01 \mu\text{g}/\text{m}^3$	$28.8 \mu\text{g}/\text{m}^3$	30 days = 2,880 segments of 15 min TWA
Fire (100 lbs powder/chips), Table 5				
Term release, 0.3 cm/s dep. Vel.	Site boundary at 1,000 m (1 km)	$1.3\text{E}-4 \mu\text{g}/\text{m}^3$	$0.37 \mu\text{g}/\text{m}^3$	77 times lower than EPA limit
	200 m (0.2 km)	$3.5\text{E}-3 \mu\text{g}/\text{m}^3$	$10 \mu\text{g}/\text{m}^3$	3 times lower than EPA limit
Term release, 0 cm/s dep. Vel.	Site boundary at 1,000 m (1 km)	$4.2\text{E}-4 \mu\text{g}/\text{m}^3$	$1.2 \mu\text{g}/\text{m}^3$	24 times lower than EPA limit
	200 m (0.2 km)	$7.3\text{E}-3 \mu\text{g}/\text{m}^3$	$21 \mu\text{g}/\text{m}^3$	1.5 times lower than EPA limit
1 MW or 5 MW fire	Be concentrations at 1 km and 200 m are several orders of magnitude lower than for term release (Table 5). Public is protected.			Lofting is involved

Standard for Hazardous Air Pollutants (NESHAPs), per 40 CFR 61.32 and its subpart C which relates to Beryllium emission standard. According to 40 CFR 61.32,⁴ the Be air quality limit is 0.01 $\mu\text{g}/\text{m}^3$ averaged over a 30-day TWA, to protect the public (no CBD); which is based on a 10 g release of Be over 24-hr period. Based on calculations shown in Table 5, only term release for standard terrain is used for evaluation, as a conservative estimate. The results are shown in Table 7, which indicate that the public is protected beyond 200 m (no CBD).

SUMMARY

1. The ARF/RF values in beryllium powder are governed by the size distribution, which are about several orders of magnitude lower for explosion, fire, and spill (e.g., $1\text{E}-2$, $1.5\text{E}-5$, $1\text{E}-6$) than earlier estimates based on DOE-HDBK-3010.
2. Using a combination of 97% powder/chips and 3% dust ($<10\text{ }\mu\text{m}$) fraction with a total inventory of 100 lbs beryllium, the combined ARF/RF values for explosive release, fire (heated, ignited, combustible) and spill are evaluated for standard and city terrains.
3. Using term release and new ARF/RF ($2.35\text{E}-5$ for fire, heated), facility chemical hazard classification can be established as High, Moderate, and Low using the criteria of ERPG-3 or 2. For example, using 100 lbs powder/chips, with 0 or 0.3 cm/sec deposition velocity, and standard terrain (conservative), the facility is Low hazard based on ERPG-3 criteria; and Moderate hazard based on ERPG-2 criteria.
4. The facility CHC should be supported at a defined distance beyond which the public is protected (no CBD). This case study of 100 lbs of powder/chip, fire and term release for standard terrain shows that the Be concentrations at 200 m and beyond are below the EPA limit of 0.01 $\mu\text{g}/\text{m}^3$ on a 30-day TWA.
5. Beryllium aerosol exposure can cause two major health effects: (1) acute exposure (short term) from

ERPG-3, -2 levels; and (2) chronic (long term) from (a) sensitization and (b) CBD.

6. The beryllium TLV is 2.0 $\mu\text{g}/\text{m}^3$, however, 10 CFR 850 Rule requires a protection action level for workers at 0.2 $\mu\text{g}/\text{m}^3$ (air, 8-hr TWA exposure), which further mitigates or prevents CBD. Thus, using 40 CFR 61.32, ACGIH and OSHA guide, and 10 CFR 850 Rule, and worker protection program, the workers and public can be adequately protected from the CBD.

ACKNOWLEDGEMENTS

The authors appreciate Jim Tingey and Ray Sorter of Safety Basis Division, Jofu Mishima LANL consultant, Terry Foppe of Foppe Associates, Dave Thoman of Washington Safety Management Solution, and Steve Homann of LLNL for their technical comments.

The authors acknowledge the U.S. DOE/NNSA for support of this work. Funding for this report was provided by Stephen P. Abeln of MST-6 of LANL, which is greatly appreciated.

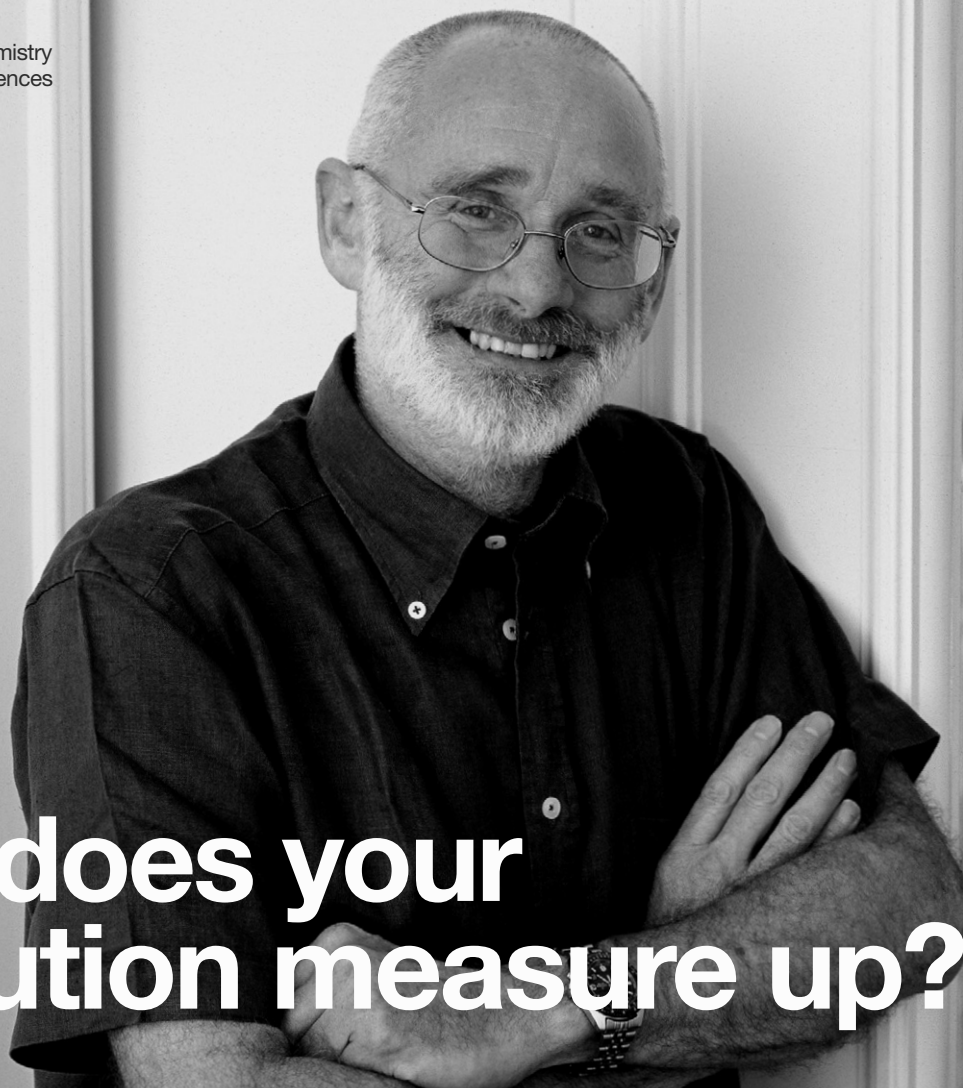
REFERENCES

1. Mishima, J.; Foppe, T. L.; Laul, J. C.; McEahern, P. M.; Pinkston, D. M.; Restrepo, Louis F. *Proposed Beryllium Metal Bounding Airborne Release Fractions (ARFs)/Rates (ARRs) and Respirable Fractions (RFs) for DOE Facility Accident Analysis*, LA-UR-05-1096, Los Alamos National Laboratory, NM, April 2005; Rev. 1, September 2006.
2. Mishima, J.; Foppe, T. L.; Laul, J. C. *Proposed Beryllium Metal Bounding Airborne Release Fractions (ARFs)/rates (ARRs) and Respirable Fractions (RFs) for DOE Facility Accident Analysis*. *J. Chem. Health Safe.*, **2008**, 15(4), 26–45.
3. DOE-HDBK-3010-94, by Mishima, J., et al., *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Change Notice 1, March 2000.
4. 40 CFR 61, EPA National Emission for Hazardous Air Pollutants (NESHAPs), Subpart C for Beryllium Emission, Subpart 61.32 Emission Standard for Beryllium, 7-1-2004.
5. ACGIH (American Conference of Government Industrial Hygienists) recommended a threshold limiting value (TLV) of 2 $\mu\text{g}/\text{m}^3$ for beryllium personal breathing zone in an 8-hr time-weighted average (TWA).
6. 10 CFR Part 850, *Chronic Beryllium Disease Prevention Program, Final Rule*, Vol. 64, No. 235, 68854-68914, December 8, 1999.
7. Wambach, P. F.; Laul, J. C. Beryllium Health Effects, Exposure Limits, and Regulatory Requirements. *J. Chem. Health Safe.*, **2008**, 15(4), 5–12.
8. Laul, J. C.; Foppe, T. L.; Mishima, J. *Applicability of Airborne Release Fraction and Respirable Fraction Values to Particulate Toxic Chemical Material Releases at DOE Sites*, LA-UR-05-8271, Chemical Health and Safety Journal, Vol. 13, No. 6, 7–11, November/December 2006.
9. Jordan, H. *Airborne Release Fractions of Beryllium Metal in a Fire – Literature Review and Recommendations*, LA-13843-MS, Los Alamos National Laboratory, NM, September 2001.
10. Laul, J. C., Beryllium: Airborne Release Fractions, Properties, Facility Chemical Hazard Characterization, and Health Effects During Be Releases (Accidents, LA-CP-07-0326, Los Alamos National Laboratory), March 2007.
11. Adams, R. O.; Hurd, J. T. The Properties of Beryllium Surfaces and Films. *J. Less-Common Metals*, **1969**, 18, 399–409.
12. Blumenthal, J. L.; Santy, M. J. (TWR), *An Experimental Investigation of the Behavior of Beryllium in Simulated Launch Pad Abort Environments*, Final Report (Prepared for Sandia National Laboratory and the TWR Corp.), January 1964.
13. Lindsay, J. W.; Robinson, H. N. *Oxidation and Ignition Behavior of Beryllium Metal*, Report No. CRDL 940612-00, the Dow Chemical Company-Rocky Flats Division, Golden, CO, November 1970.
14. Laul, J. C.; Simmon, F.; Goss, J. E.; Boada-Clista, L. M.; Vrooman, R. D.; Dickey, R. L.; Spivey, S. W.; Stirrup, T.; Davis, W. Perspectives on chemical hazard characterization and analysis process at DOE. *J. Chem. Health Safety*, **2006**, 3(4), 6–39.
15. AIHA (American Industrial Hygiene Association), Emergency Response Planning Guidelines for Beryllium, ERPG-1, -2, -3, 1998.
16. EPIcode, *Emergency Prediction Information Code*, Version 7.0 User Documentation, Online Help distributed

- with software package, Homann Associates, Inc., September 2003.
17. ALOHA, *Areal Location of Hazard Atmospheres*, 5.2.3 *User's Manual*, Office of Response and Restoration of the National Oceanic and Atmospheric Administration (NOAA) and Chemical Emergency Preparedness and Prevention Office (CEPPO) and the US Environmental (EPA), Seattle, WA, 1999.
 18. Bruce, T. D. *Workbook of Atmospheric Dispersion Estimates*, 2nd ed. U.S. National Air Pollution Control Administration; Cincinnati, OH, 1969.
 19. Chung, D. Y.; O'Kula, K. R. *Accident Analysis Guidance for Completion of 10 CFR 830 Compliance DSAs*, EFCOG, Oak Ridge, TN, June 22–27, 2002.
 20. DOE-EH-4.2.1.3, *Computer Code Application Guidance for Documented Safety Analysis for EPLcode Code*, June 2004.
 21. DOE-EH-4.2.1.3, *Computer Code Application Guidance for Documented Safety Analysis for ALOHA Code*, June 2004.
 22. Craig, D. K.; Davis, J. S.; Lee, L. G.; Prowse, J.; Hoffman, P. W. *Toxic Chemical Hazard Classification and Safety Evaluation Guidelines for Use in DOE Facilities*, WSRC-MS-92-206, Rev. 3, December 2000.
 23. Craig, D. K.; Lux, C. R. *Methodology for Deriving Temporary Emergency Exposure Limits (TEELs)*, WSRC-TR-98-00080. Westinghouse Savannah River Company, Aiken, SC, 1998.

“As financial resources become more scarce, it is more critical to identify research and researchers who are the most productive and on the right track.”

Peter Brimblecombe
Professor, Atmospheric Chemistry
School of Environmental Sciences
University of East Anglia, UK



How does your institution measure up?

Scopus is the optimal data source for research performance measurement. No other database has so much breadth of content covering so many authors.

With Scopus you can identify authors' papers, track their citations and analyze their influence using the Scopus *h-index*. And, to evaluate the performance of journals, research projects and groups of researchers you can measure the performance of a specified collection of articles.

Now it's easy to:

- Evaluate and prioritize resource allocation by departments or fields
- Make informed decisions about tenure and promotion
- Promote your institution for funding and recruitment

www.scopus.com

refine your research
SCOPUS™

A woman dances with her son

**because of brain surgery that
reduced her epileptic seizures**

**performed by a neurosurgeon who was
able to pinpoint the foci of the seizure**

**due to breakthroughs in the
mapping of the human brain**

**advanced by physicians, mathematicians
and computer engineers around the world**

**inspired by new discoveries
in imaging technologies**

**reported in medical and
scientific publications.**



Building Insights. Breaking Boundaries.™

The creation of knowledge depends on a continuous line of connections between people and ideas. That's why, for over a century, Elsevier has linked researchers and practitioners worldwide to the best and newest thinking in their fields. As a professional publisher of scientific and medical information, Elsevier facilitates the review, selection, dissemination and preservation of information, publishing thousands of journals and books and providing access to a world of information via the desktop or PDA. After all, we believe that getting the right information into the right hands can make a difference. elsevier.com